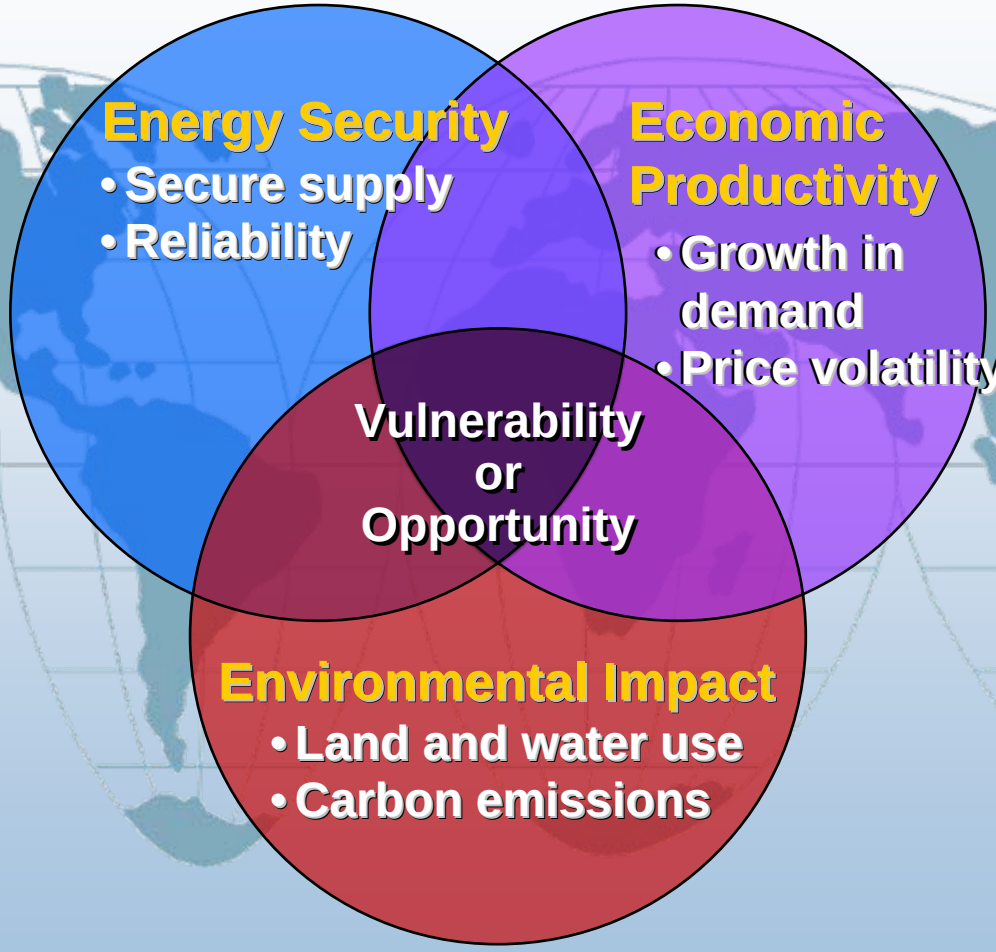
Alternative Energy: Solar, Wind, Geothermal

Milken/Sandia Energy Workshop for Financial and Capital Market Leaders

October 23, 2007

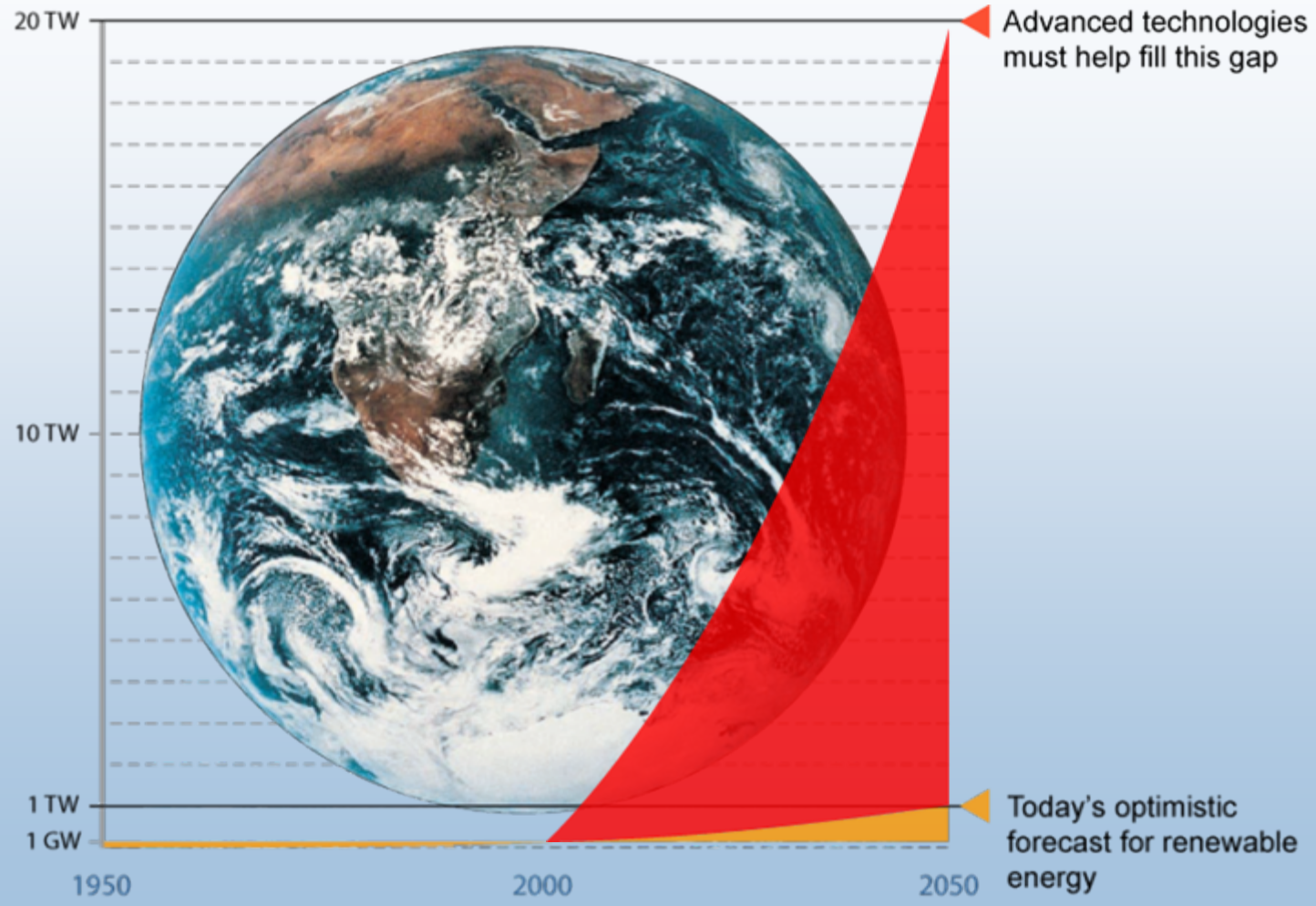
Dan E. Arvizu
Director, National Renewable Energy Laboratory

Energy Solutions Are Enormously Challenging



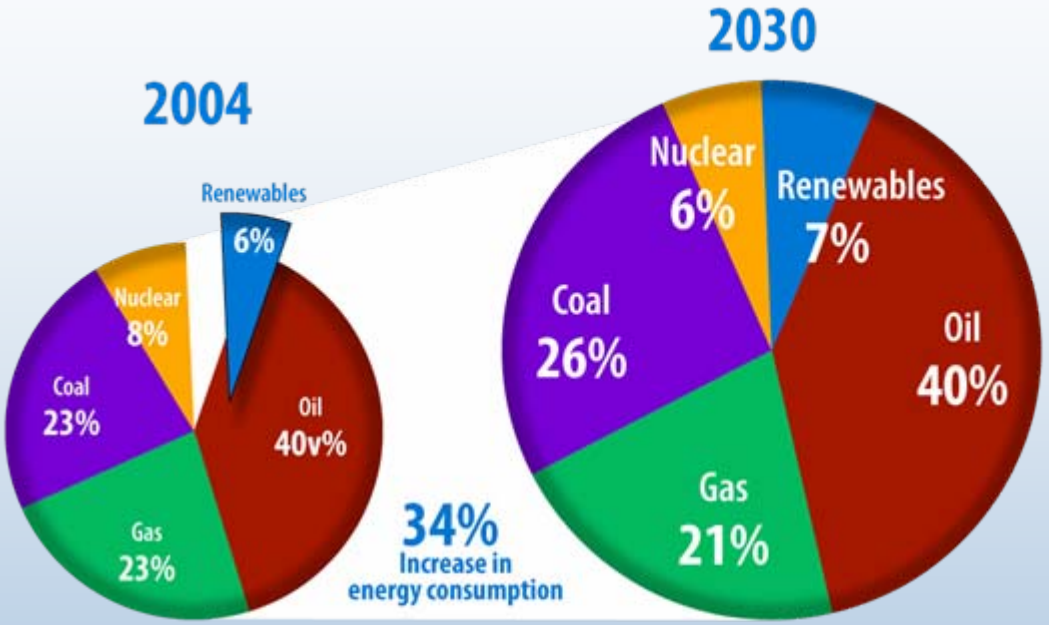
Must address all three imperatives

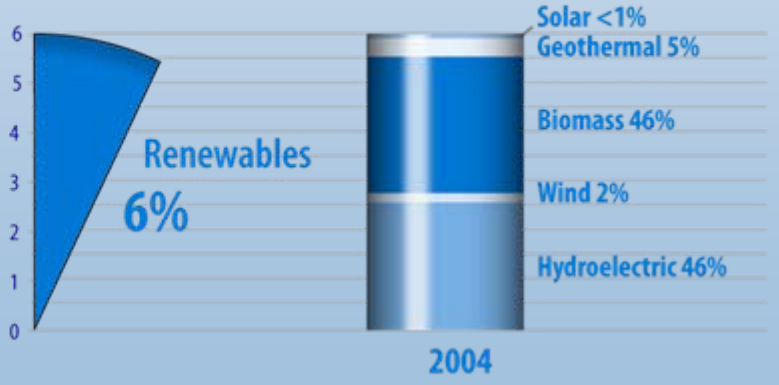
How Big is the Challenge?



Source: Arvizu, NREL

U.S. Energy Consumption and the Role of Renewable Energy



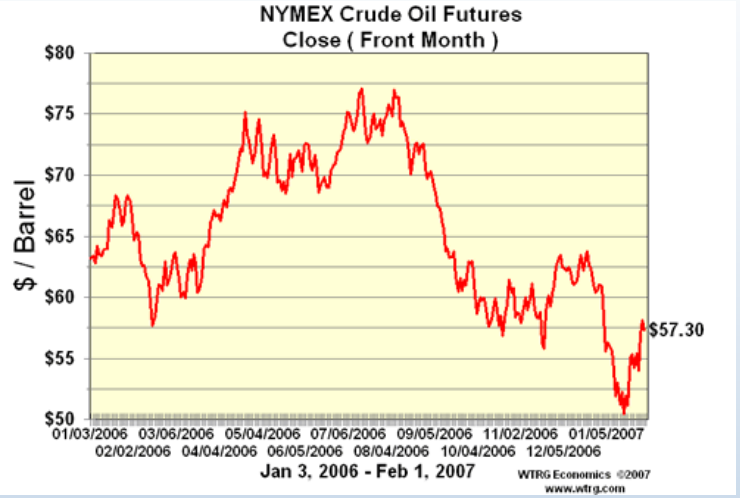


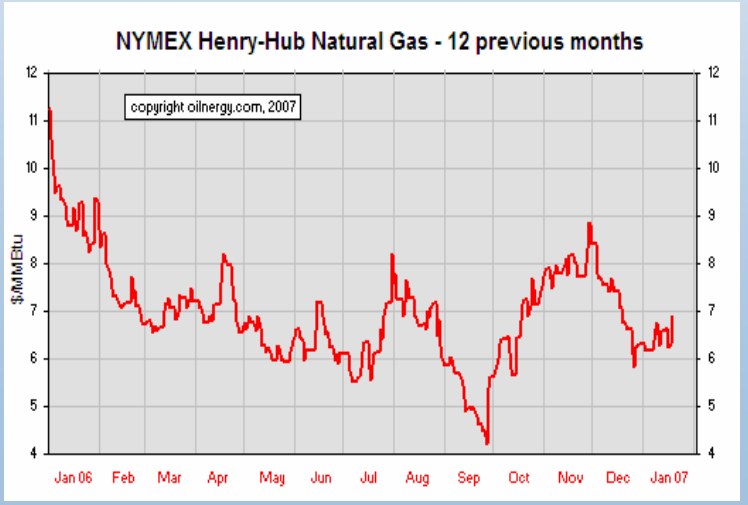
Source: Energy Information Administration, *Annual Energy Outlook 2006,* Table D4

Thinking Differently: Account for Externalities

Today's energy marketplace does not appropriately "value" certain public objectives or social goods, instead we have:

- Price volatility
- Serious environmental impacts
- Underinvestment in energy innovation



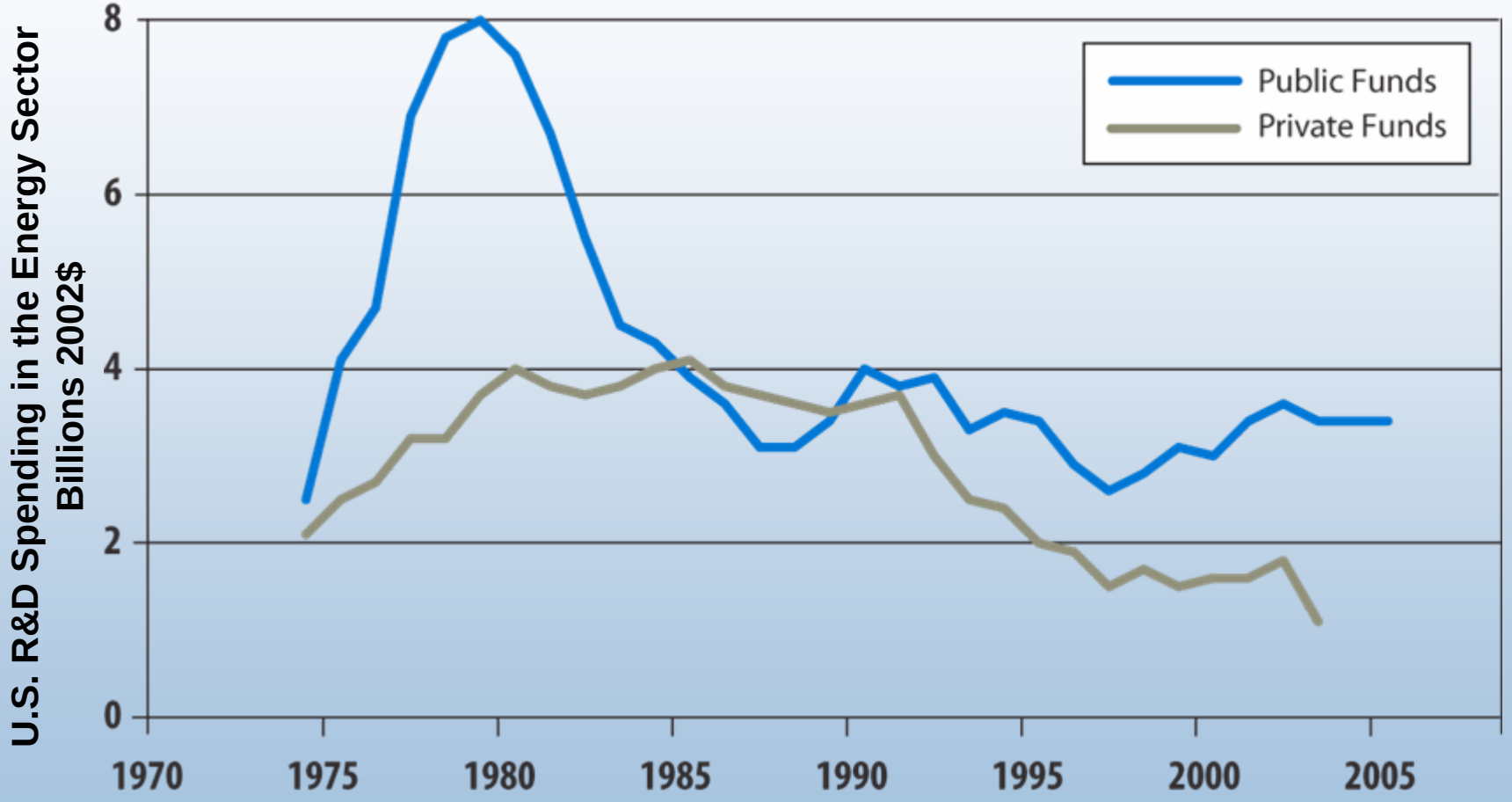


Mounting Evidence



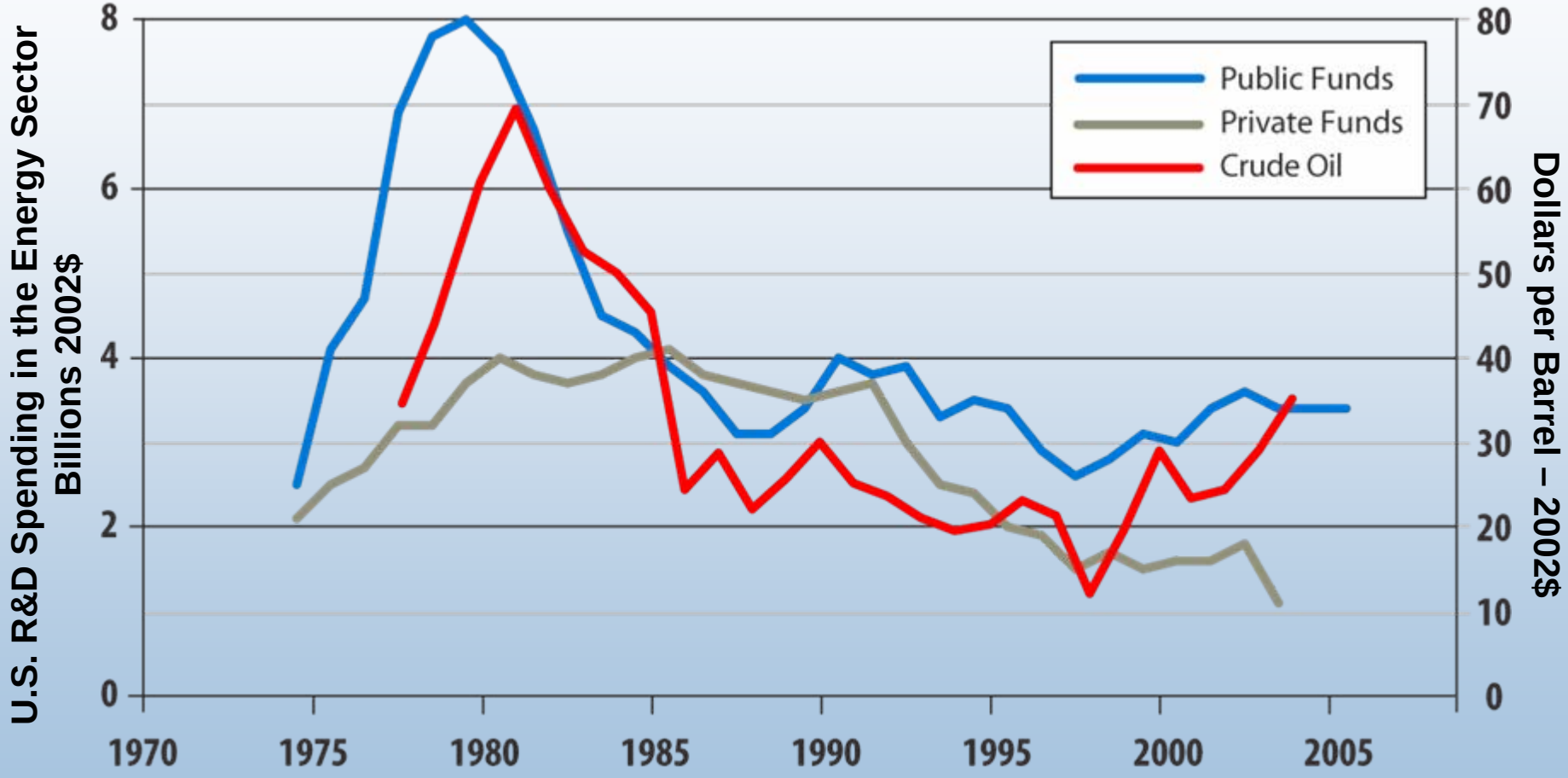



Declining Energy R&D Investments…



Source: Daniel Kammen, Gregory Nemet *Reversing the Incredible, Shrinking Energy R&D Budget* http://rael.berkeley.edu/files/2005/Kammen-Nemet-ShrinkingRD-2005.pdf
Table 10.3, Edition 25, *Transportation Energy Data Book* http://cta.ornl.gov/data/chapter10.shtml

Declining Energy R&D Investments… Reflect World Oil Price Movement



Source: Daniel Kammen, Gregory Nemet *Reversing the Incredible, Shrinking Energy R&D Budget* http://rael.berkeley.edu/files/2005/Kammen-Nemet-ShrinkingRD-2005.pdf
Table 10.3, Edition 25, *Transportation Energy Data Book* http://cta.ornl.gov/data/chapter10.shtml

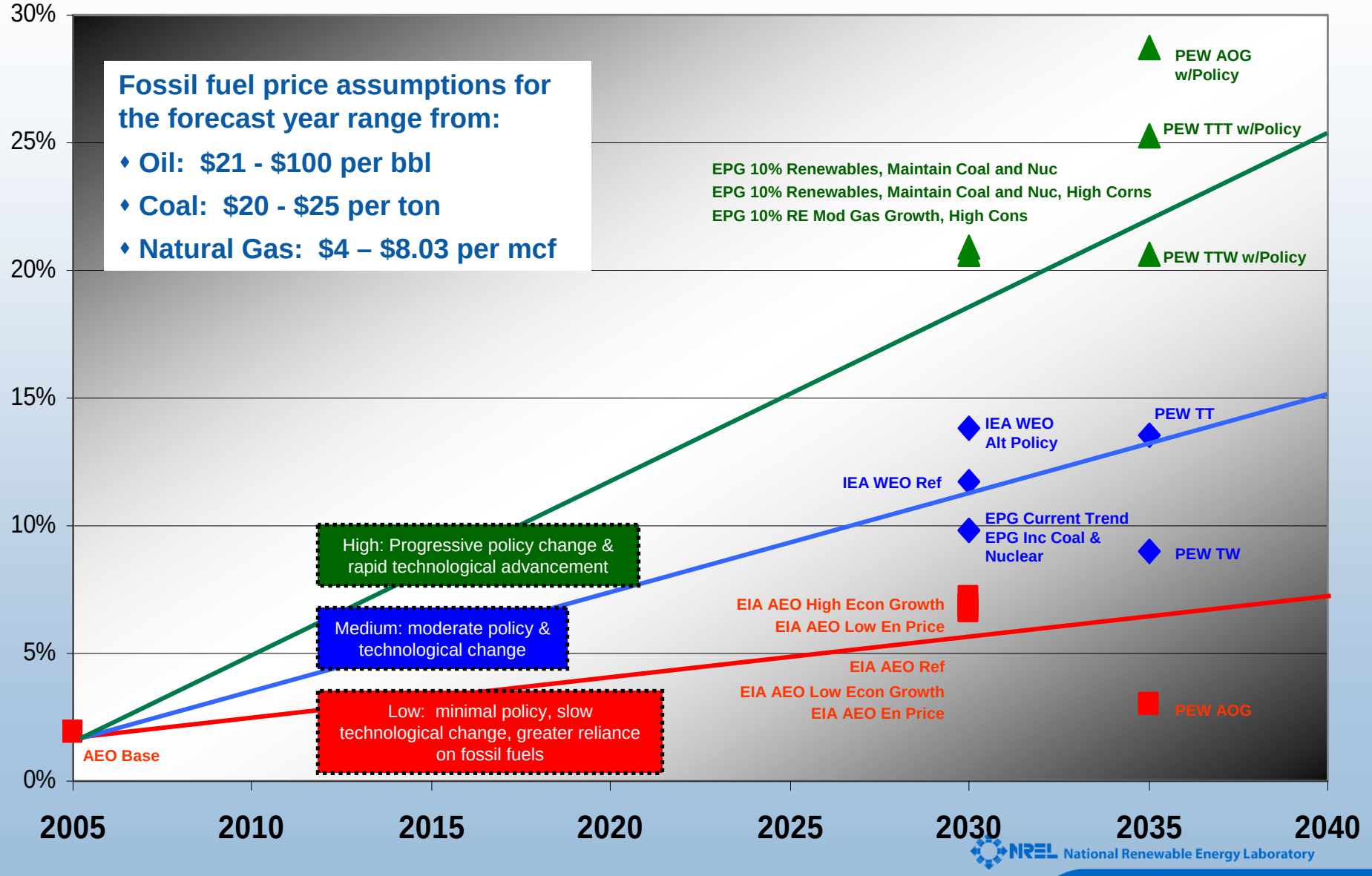
We Are Now Setting Aspirational Goals – Setting the Bar Higher

U.S. national goals

- Biofuels: reduce gasoline usage by 20% in ten years
- Wind: 20% of total provided energy by 2030
- Solar: Be market competitive by 2015 for PV and 2020 for CSP

U.S. Renewable Energy Contributions

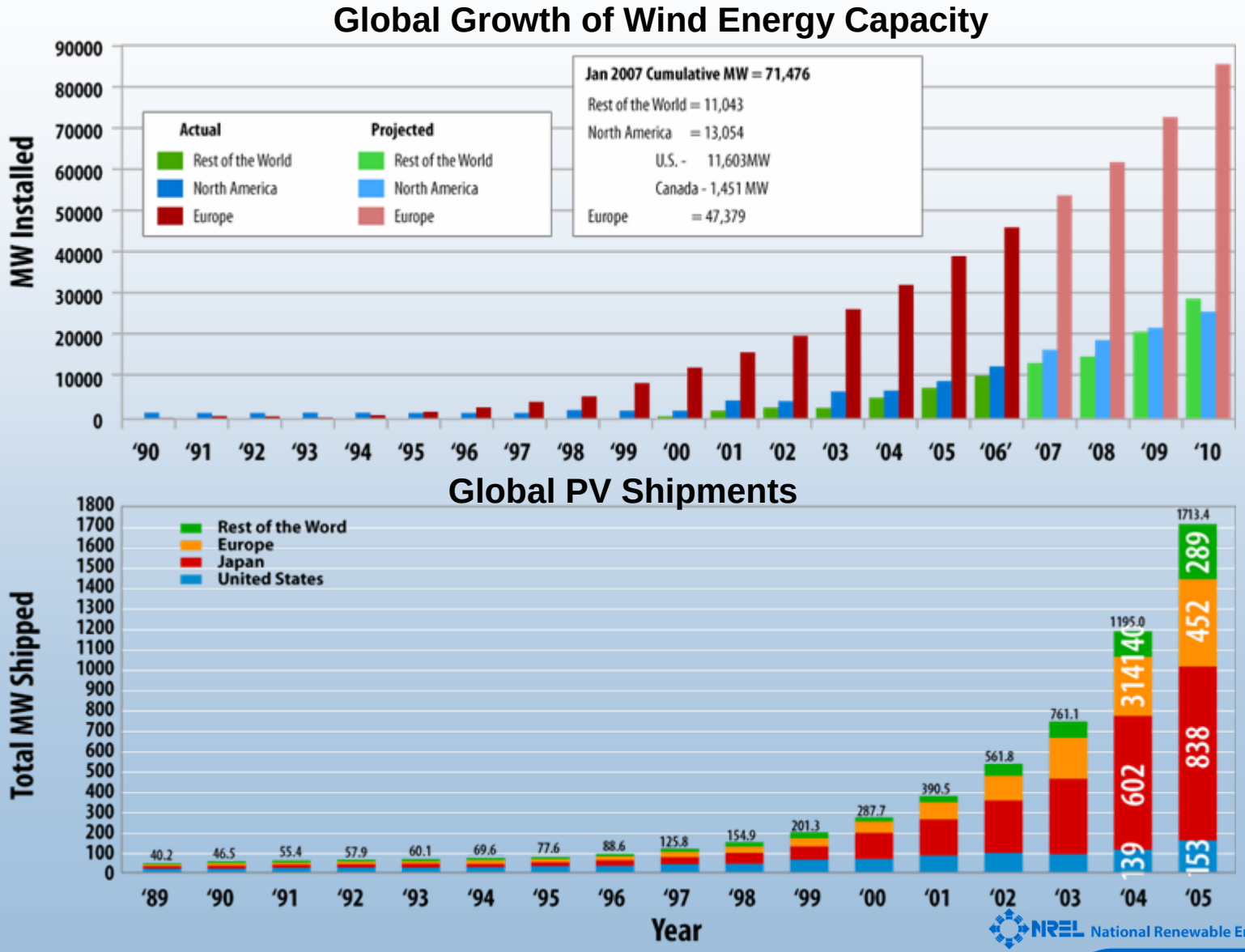
Percent of Total Electric Generating Capacity



Getting to “Significance” Involves…

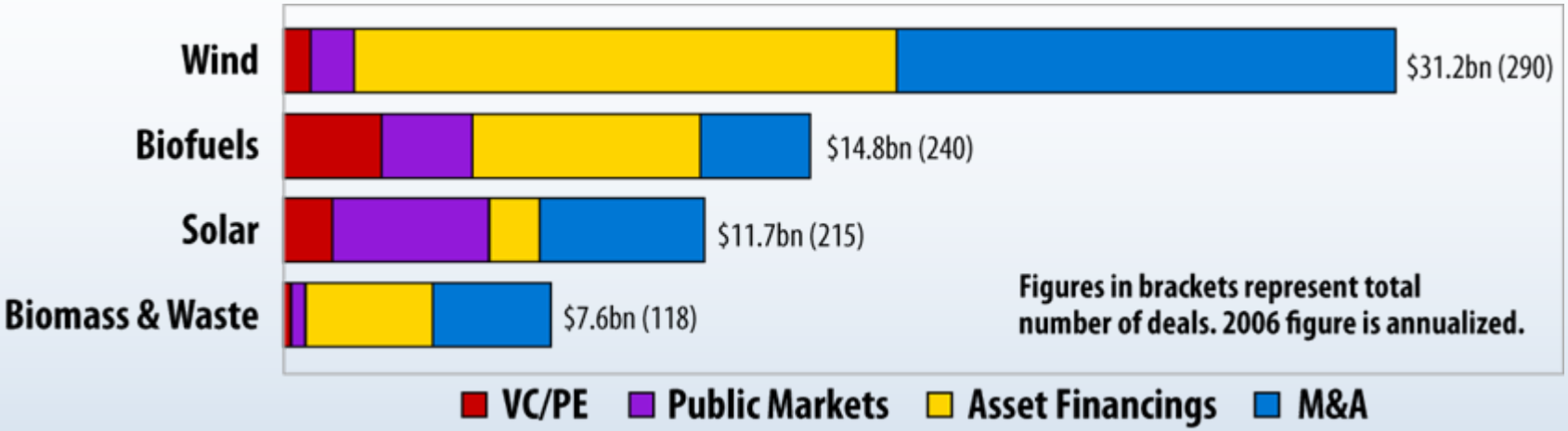
Source: NREL

Global Markets are Growing Rapidly

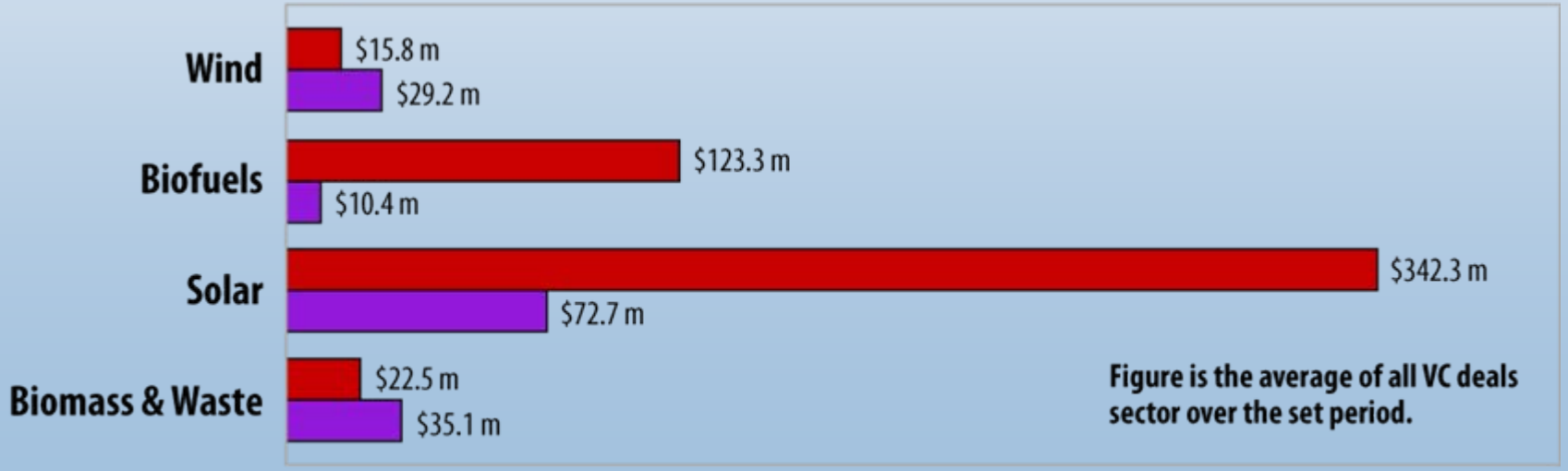


Money Is Flowing Into the Sector

2006 Investment and M&A – By Sector and Asset Class

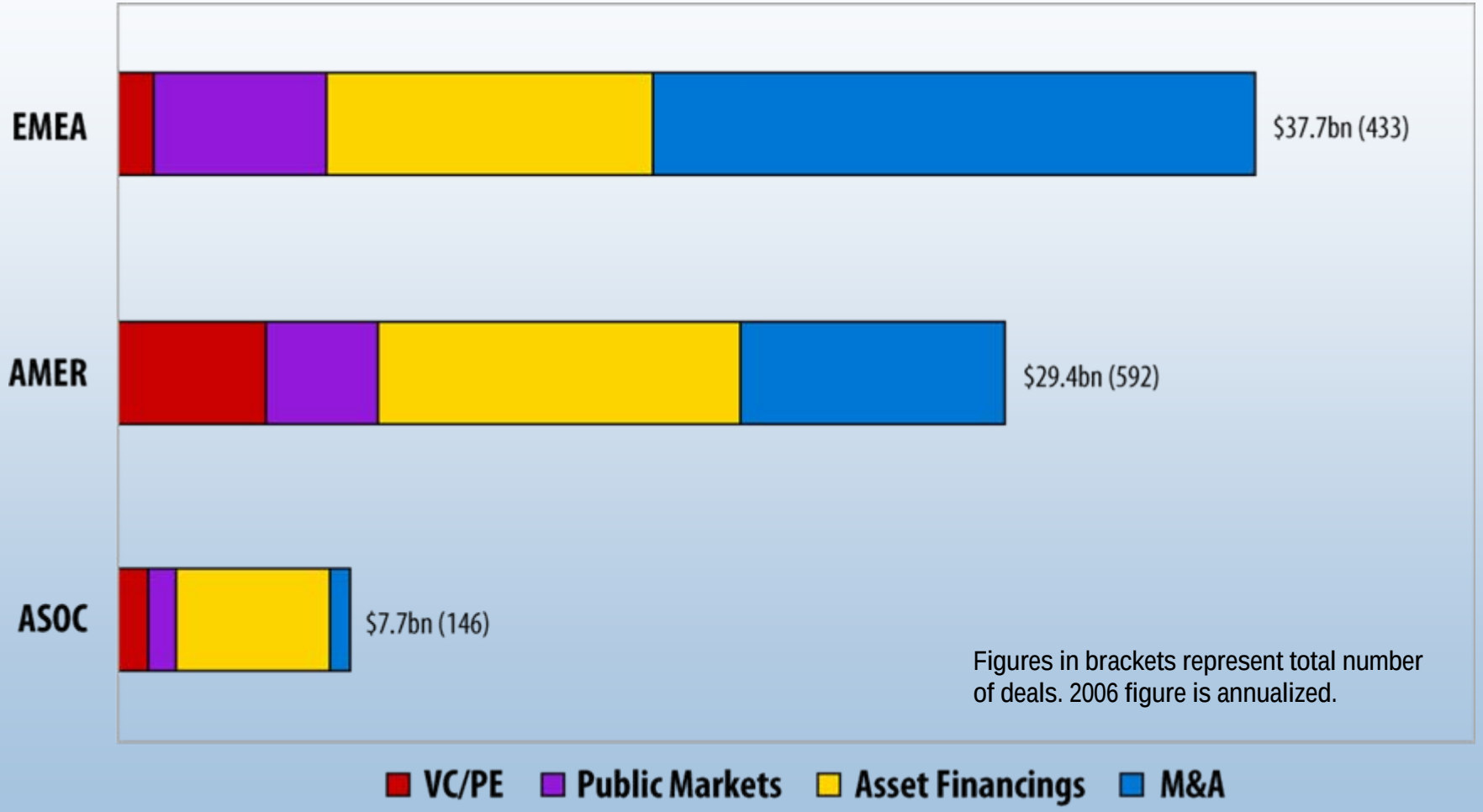


Annual VC Investment Volume – 2001-2004 Compared With 2005-2006



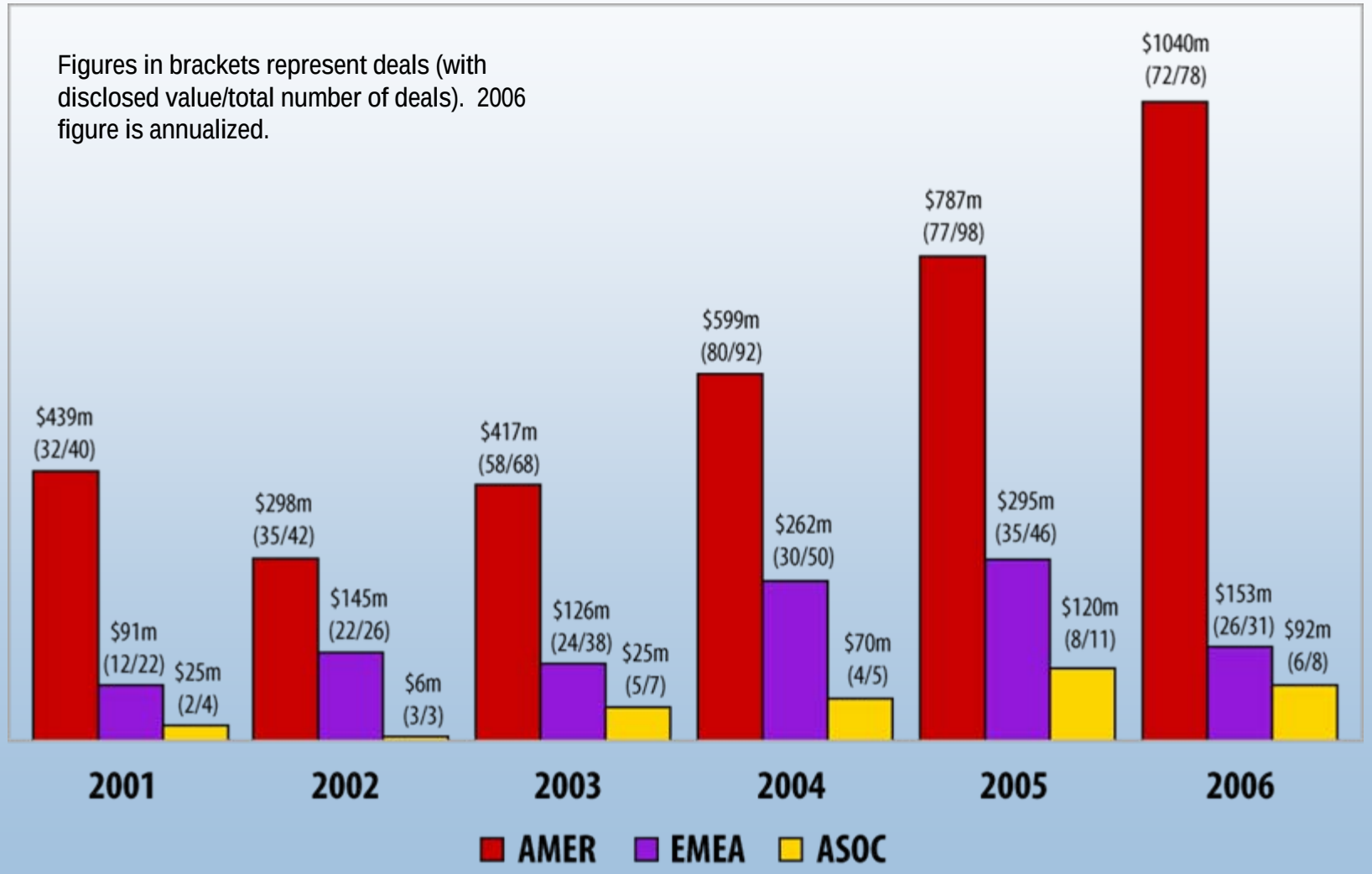
Source: New Energy Finance 2007

Investment and M&A
By Region and Asset Class – 2006



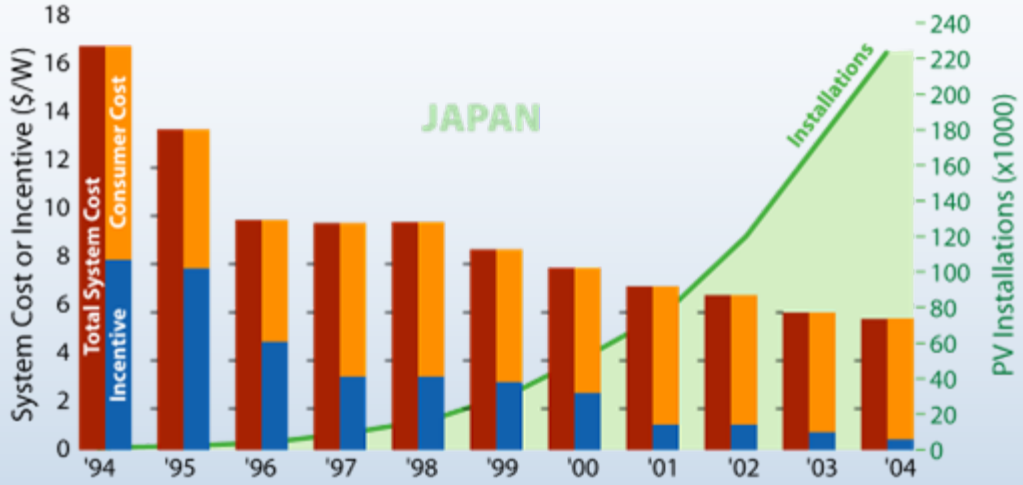
Source: New Energy Finance 2007

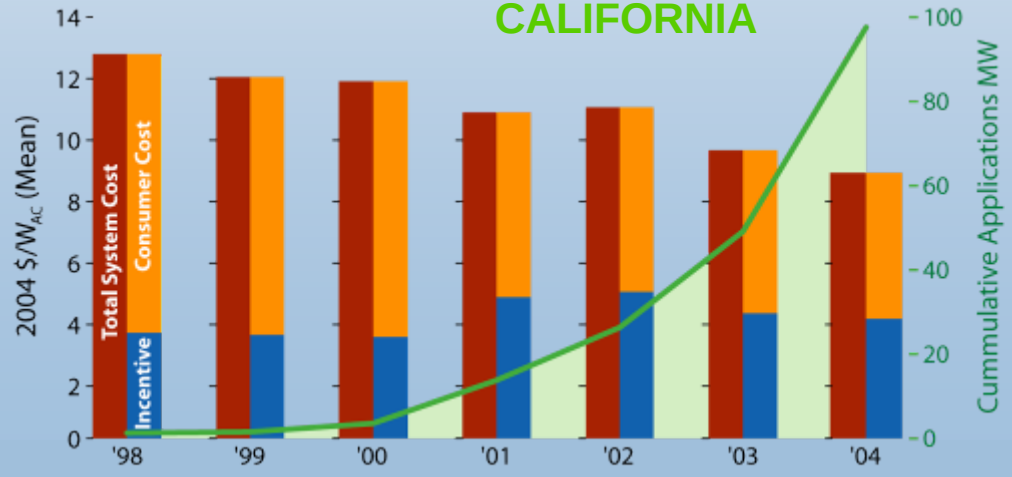
Total Estimated VC Investment by Region 2001-2006

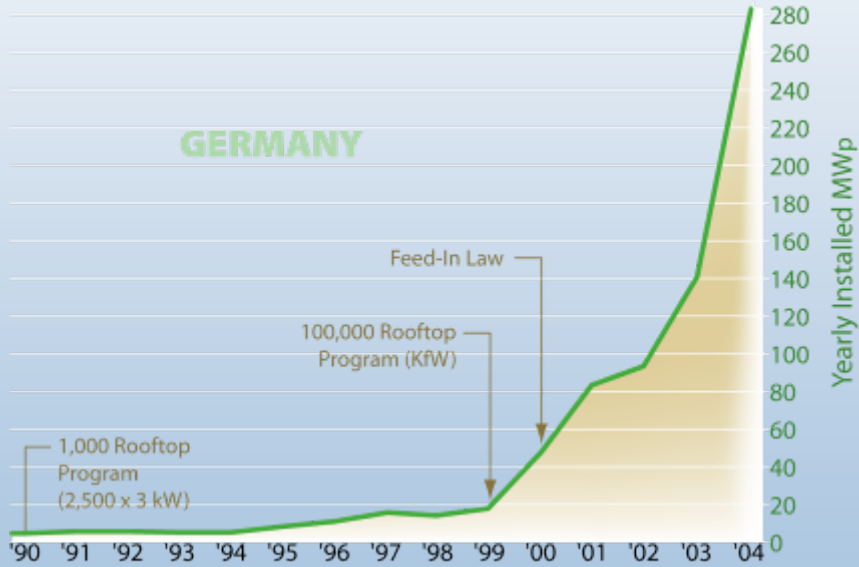


Source: New Energy Finance, January 2007

Worldwide Markets Have Driven Cost Reductions – Solar PV Example

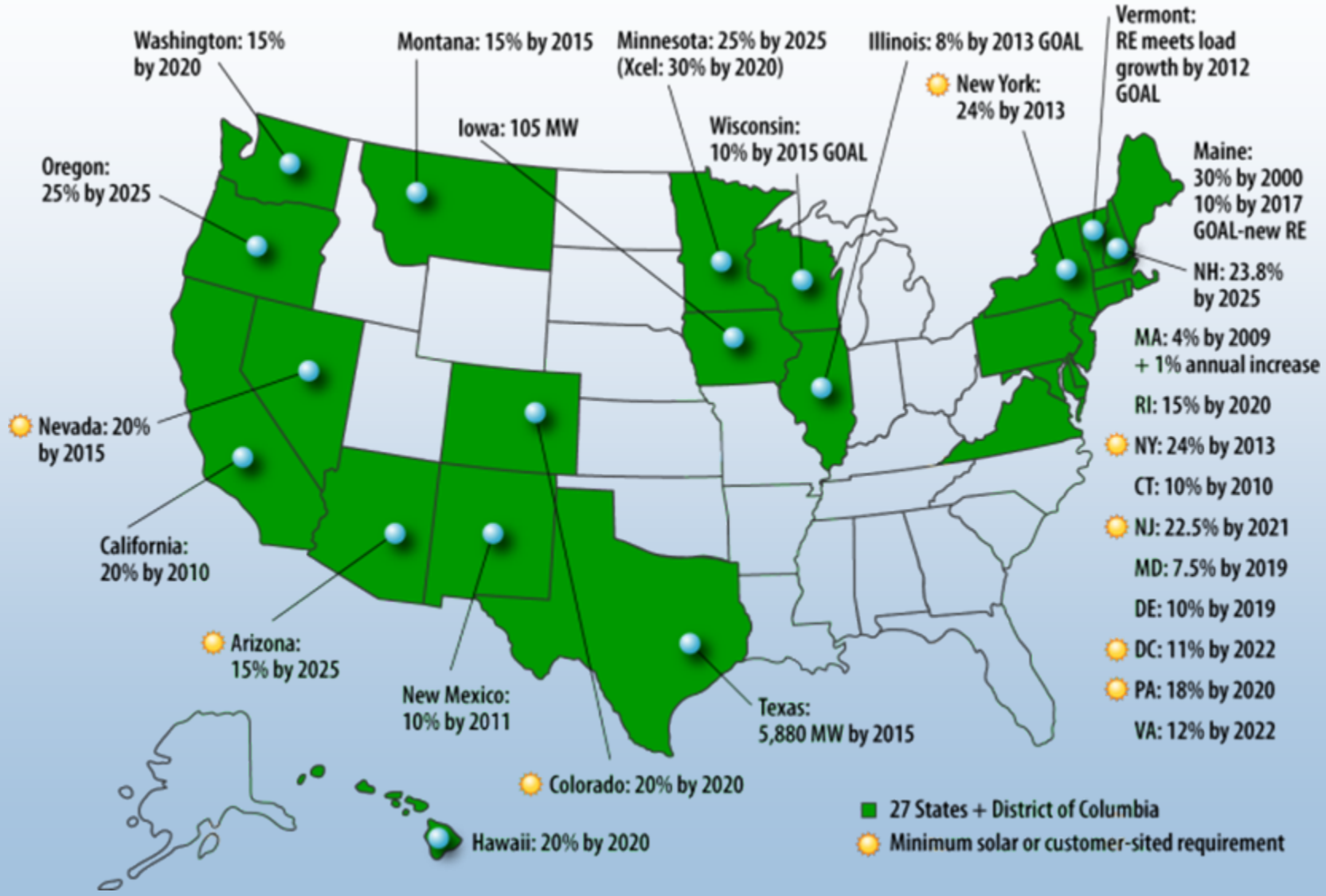






State Policy Framework

Renewable Electricity Standards



Source: DSIRE database, July 2007

Energy Efficiency and Renewable Energy Technology Development Programs

NREL R&D Portfolio

Efficient Energy Use

- Vehicle Technologies
- Building Technologies
- Industrial Technologies

Renewable Resources

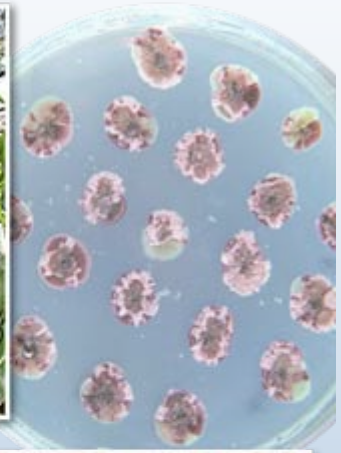
- Wind
- Solar
- Biomass
- Geothermal

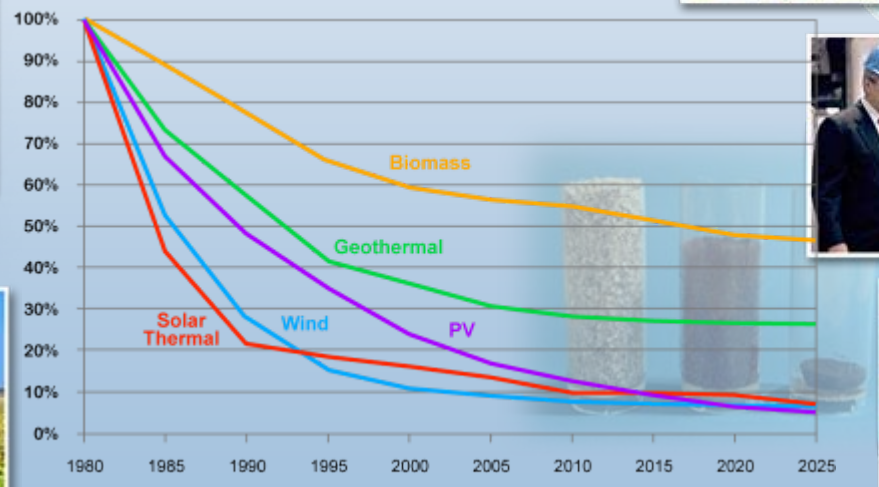
Energy Delivery and Storage

- Electricity Transmission and Distribution
- Alternative Fuels
- Hydrogen Delivery and Storage

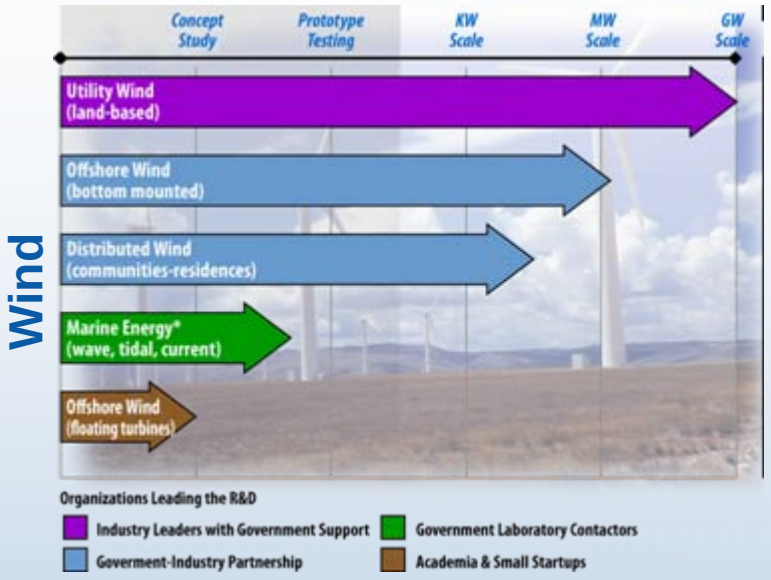
Foundational Science and Strategic Analysis

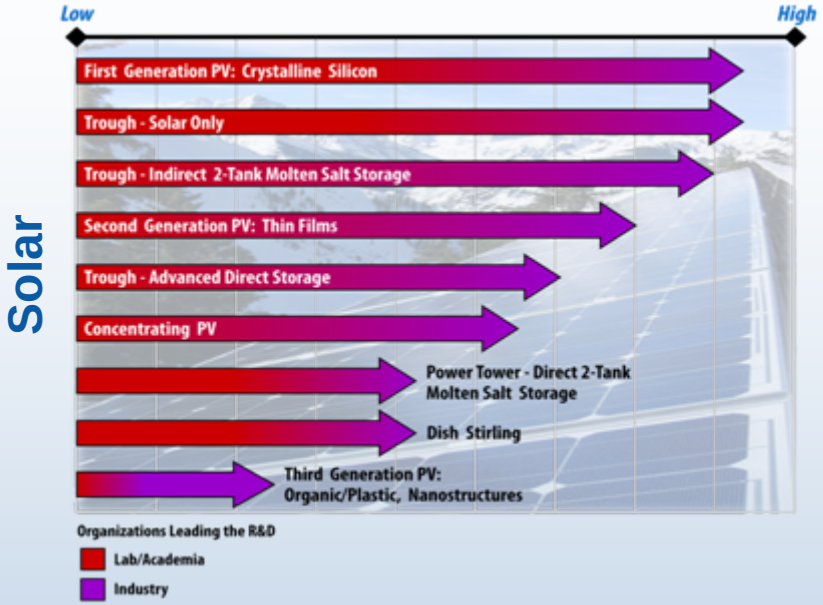
Past Investments Have Yielded Impressive Cost Reductions

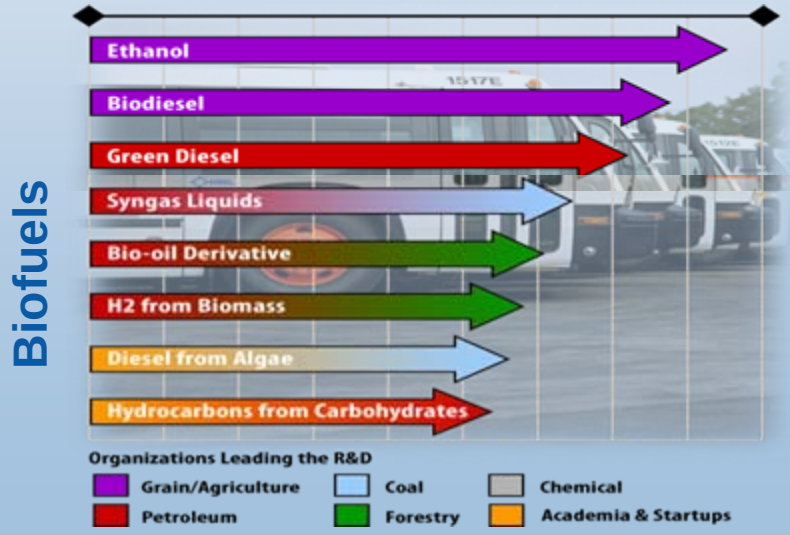


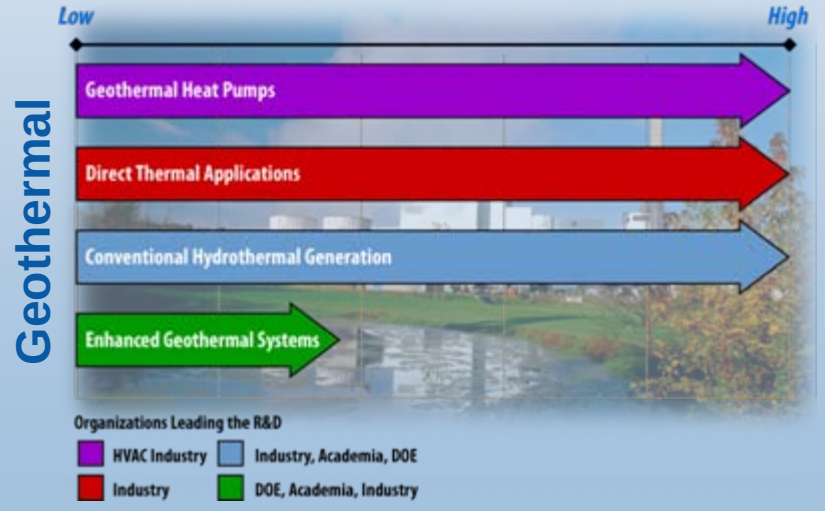


Technology Maturity Pathways









Wind

Today's Status in U.S.

- 11,603 MW installed at end of 2006
- Cost 6-9¢/kWh at good wind sites*

DOE Cost Goals

- 3.6¢/kWh, onshore at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014

Long Term Potential

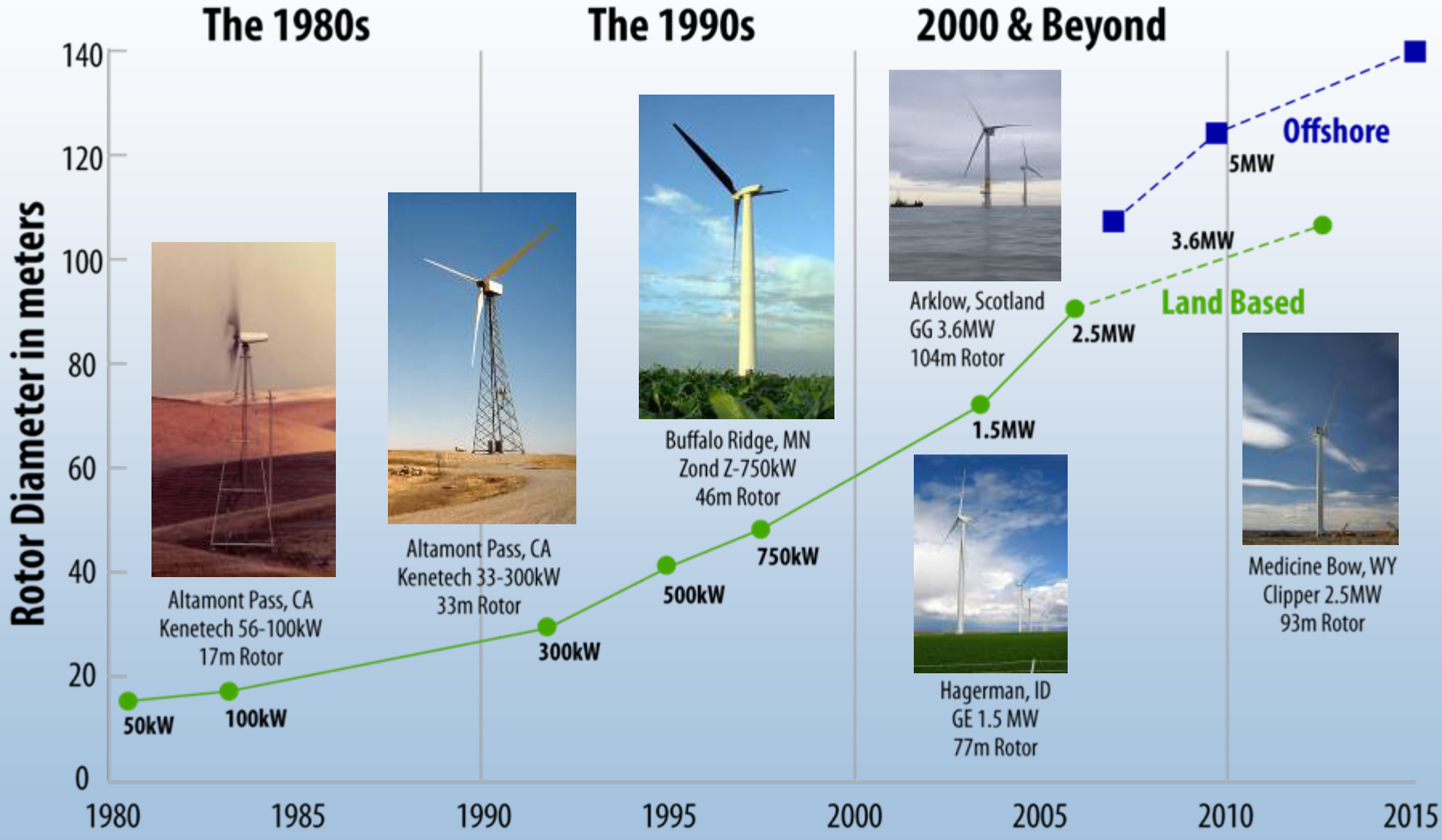
- 20% of the nation's electricity supply

NREL Research Thrusts

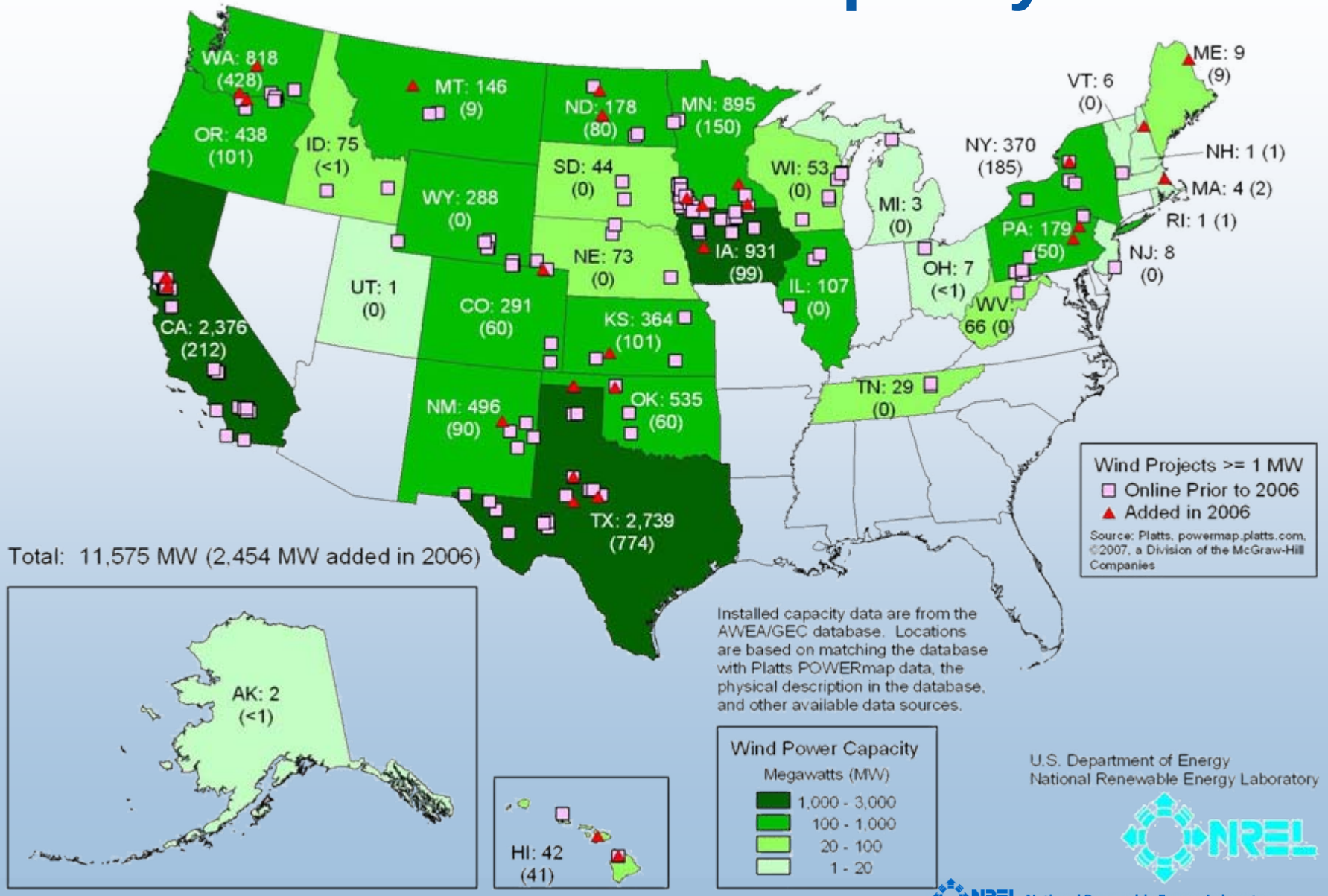
- Improved performance and reliability
- Distributed wind technology
- Advanced rotor development
- Utility grid integration

* With no Production Tax Credit
Updated 1/07, validated 7/07
Source: U.S. Department of Energy, American Wind Energy Association

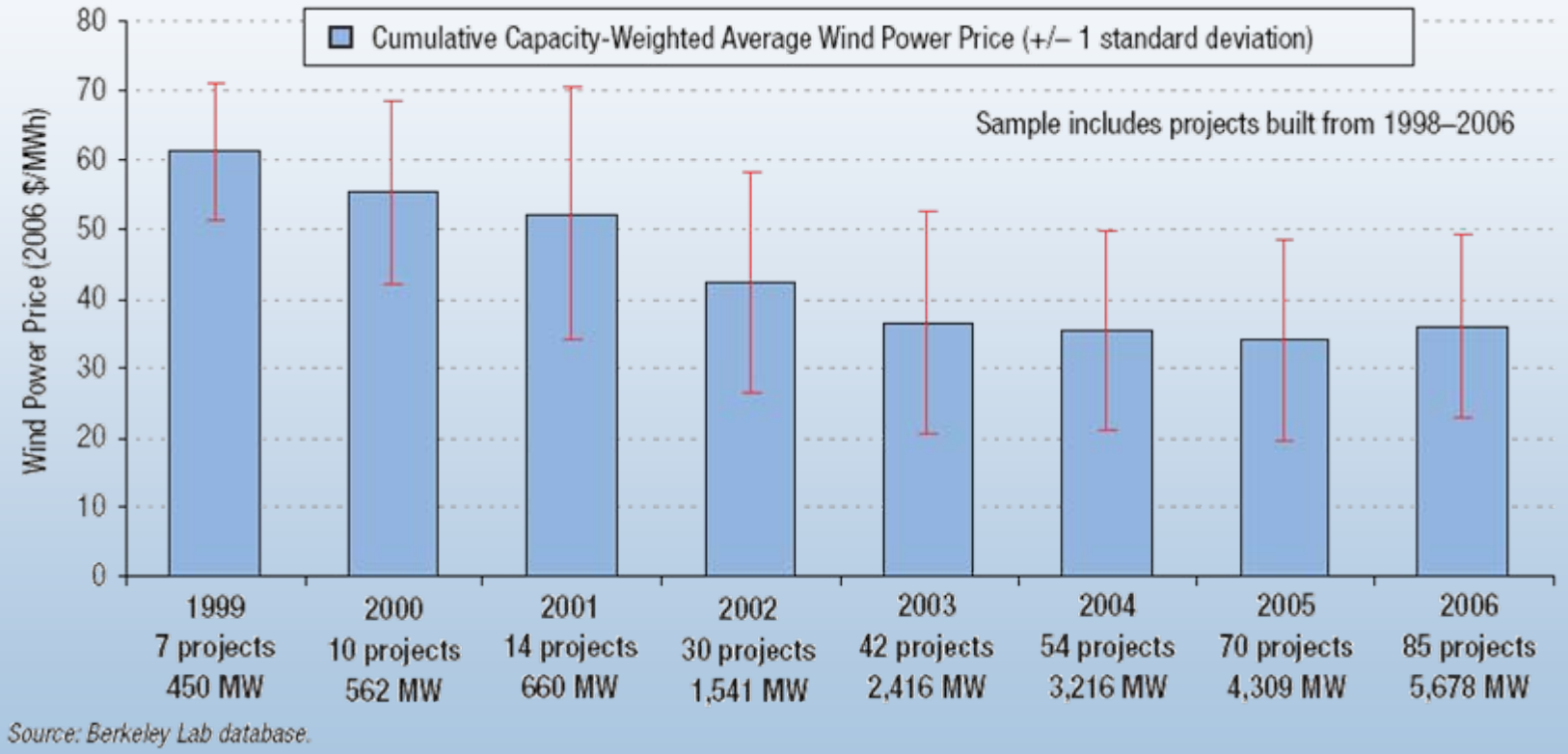
Evolution of U.S. Commercial Wind Energy



Installed Wind Capacity



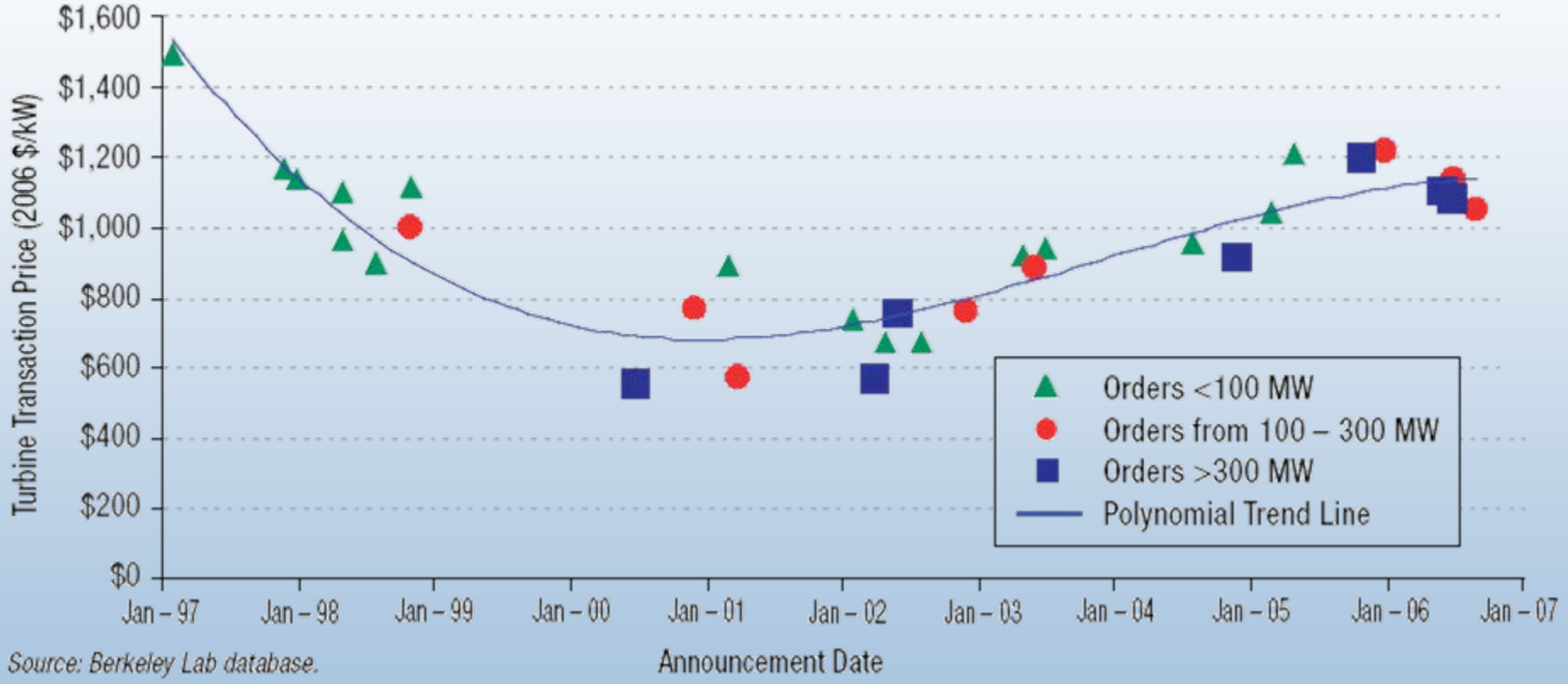
Wind Power Prices Are Up in 2006



Source: Berkeley Lab database.

Cumulative Capacity-Weighted Average Wind Power Price Over Time

Project Cost Increases Are a Function of Turbine Prices



Reported U.S. Wind-Turbine Transaction Prices Over Time

Integrating Wind Into Power Systems

New studies find integrating wind into power systems is manageable, but not costless

Date	Study	Wind Capacity Penetration	Cost ($/MWh)				
			Regulation	Load Following	Unit Commitment	Gas Supply	TOTAL
2003	Xcel-UWIG	3.5%	0	0.41	1.44	na	1.85
2003	We Energies	4%	1.12	0.09	0.69	na	1.90
2003	We Energies	29%	1.02	0.15	1.75	na	2.92
2004	Xcel-MNDOC	15%	0.23	na	4.37	na	4.60
2005	PacifiCorp	20%	0	1.6	3	na	4.60
2006	CA RPS (multi-year)	4%	0.45*	trace	na	na	0.45
2006	Xcel-PSCo	10%	0.2	na	2.26	1.26	3.72
2006	Xcel-PSCo	15%	0.2	na	3.32	1.45	4.97
2006	MN-MISO 20%	31%	na	na	na	na	4.41**

* *3-year average* ** *highest over 3-year evaluation period*

Key Results from Major Wind Integration Studies Completed 2003-2006

Some Additional Reserves May Need to be Committed

Reserve Category	Base		15% Wind		20% Wind		25% Wind	
	MW	%	MW	%	MW	%	MW	%
Regulating	137	0.65%	149	0.71%	153	0.73%	157	0.75%
Spinning	330	1.57%	330	1.57%	330	1.57%	330	1.57%
Non-Spin	330	1.57%	330	1.57%	330	1.57%	330	1.57%
Load Following	100	0.48%	110	0.52%	114	0.54%	124	0.59%
Operating Reserve Margin	152	0.73%	310	1.48%	408	1.94%	538	2.56%
Total Operating Reserves	**1049**	**5.00%**	**1229**	**5.86%**	**1335**	**6.36%**	**1479**	**7.05%**

Source MN DOC

Estimated Operating Reserve Requirement for MN BAs – 2020 Load

Solar

Photovoltaics and Concentrating Solar Power

Status in U.S.

PV
- 565 MW
- Cost 18-23¢/kWh

CSP
- 420 MW
- Cost 12¢/kWh

Potential:

PV
- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

CSP
8.5¢/kWh by 2010
5-7¢/kWh by 2020

Source: U.S. Department of Energy, IEA, Solar Energy Technologies Program Multi-Year Plan 2007

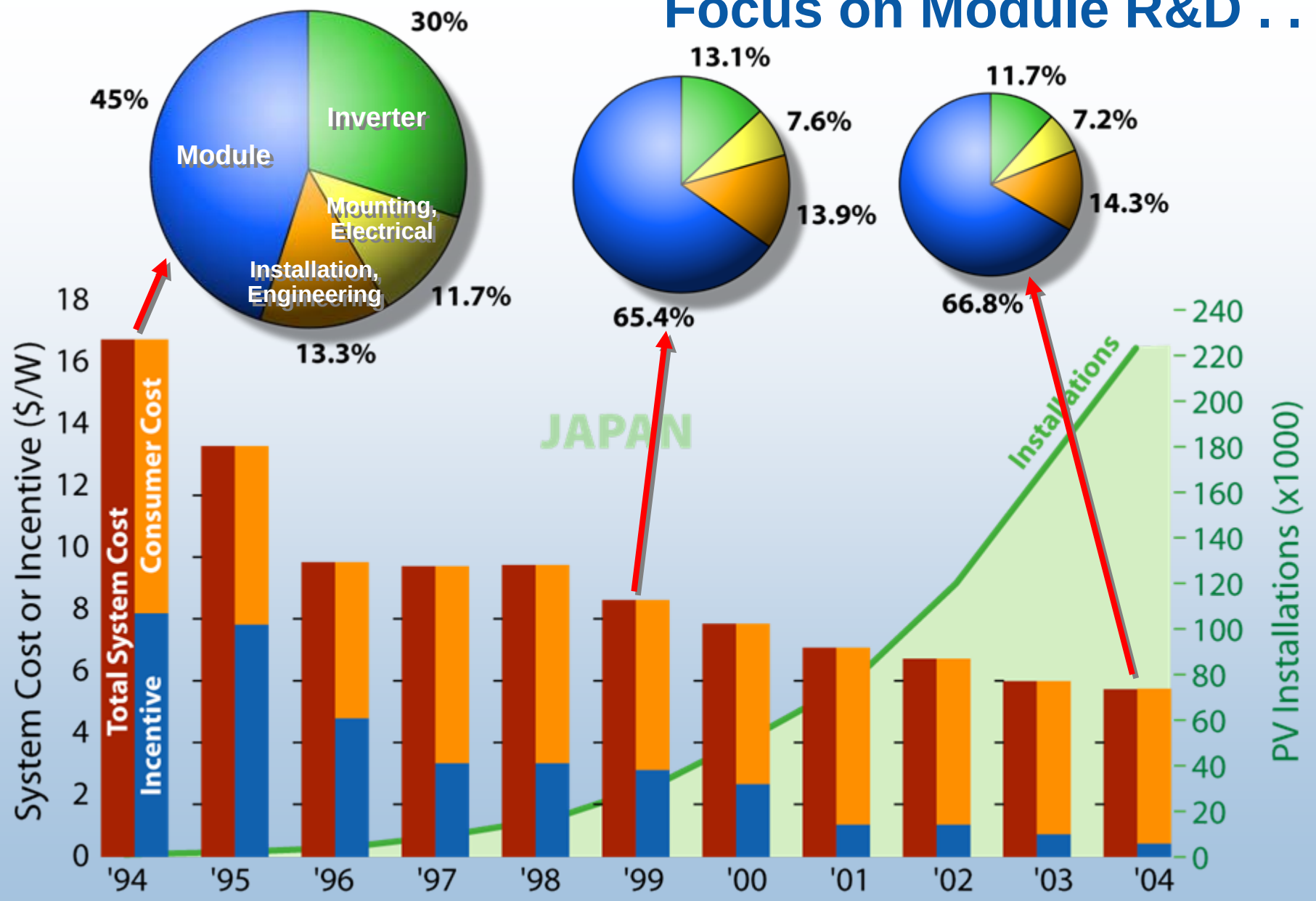
Updated July 2007

NREL Research Thrusts:

PV
- Partnering with industry
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

CSP
- Next generation solar collectors
- High performance storage

Focus on Module R&D . . .

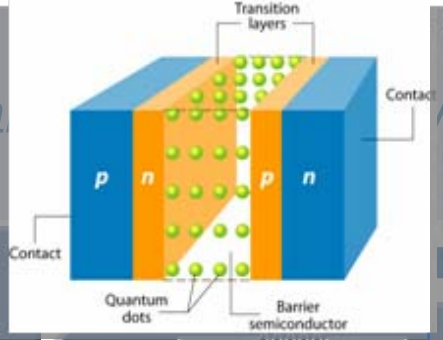


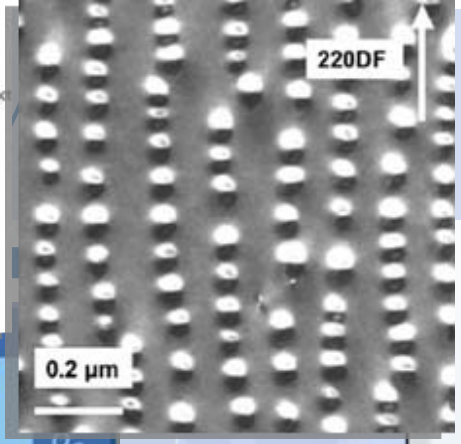
R&D

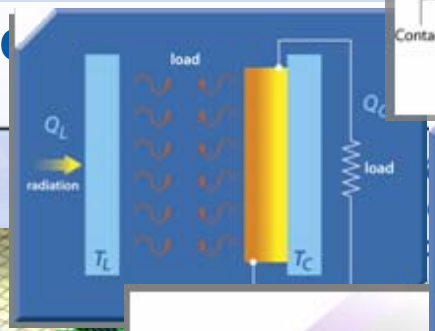
Ensures technology ownership, ena

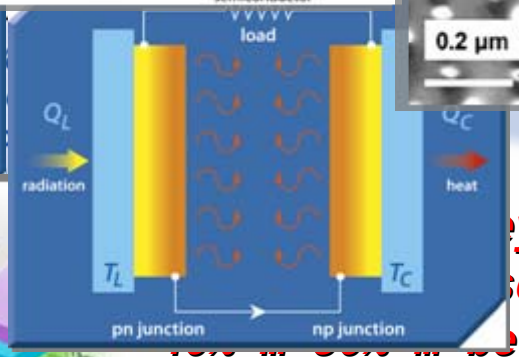
DOE is the STEWARD

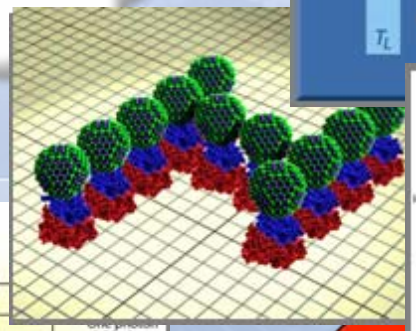
PV Module Pr

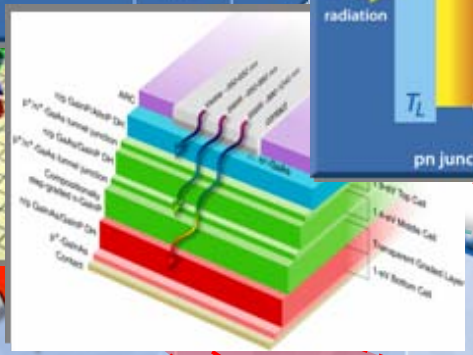


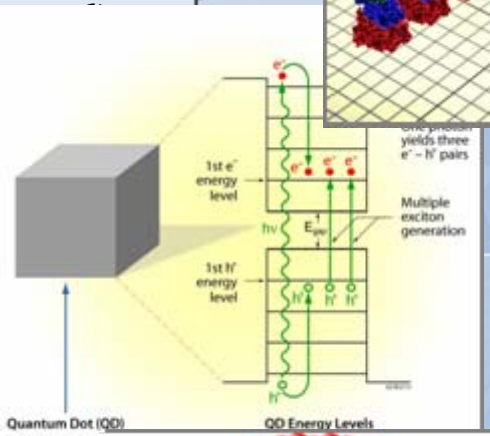


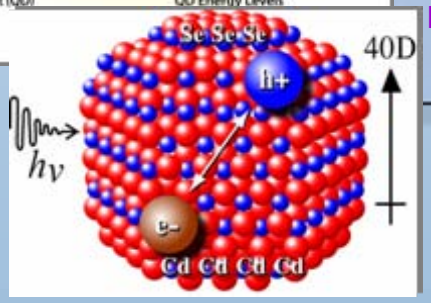












(2004$/Wp)

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10.0

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Disruptive II

3rd Gen and beyond

Quantum dots

Nanotechnology

Multi-multi-junctions

Thermophotonics, voltaics

Intermediate band . . .

90%

80%

80%

70%

60%

SEIA 2020

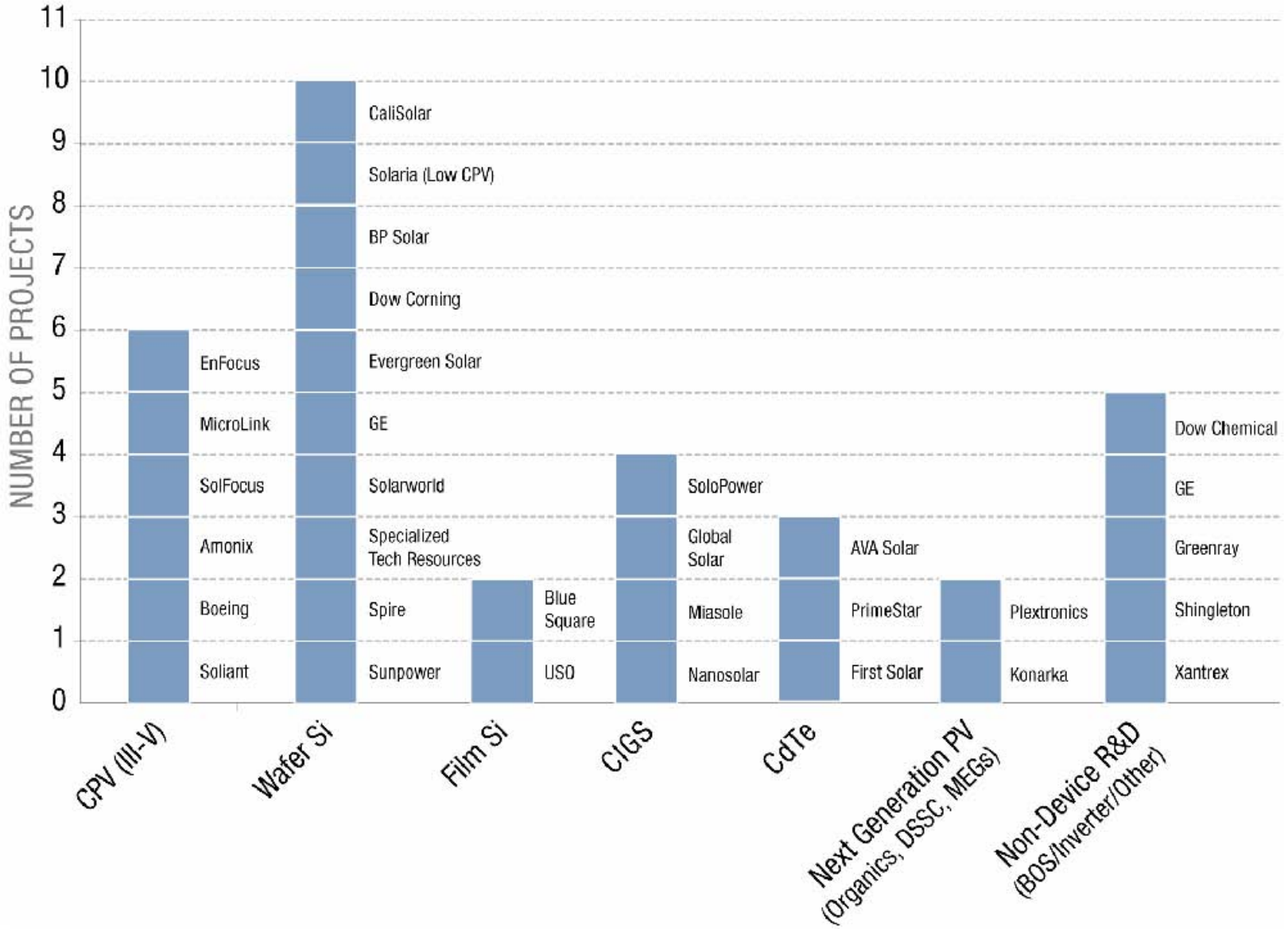
EPIA 2020

EPIA 2030

10 100 1,000 10,000 100,000 1,000,000

Cumulative Production (MWp)

DOE's Portfolio Balances Technology, Maturity & Risk, with new early-stage companies adding diversity



DOE National Lab module research balances various materials thru joint industry R&D and long-term research

4% Organic PV

Customizing organic molecules for optimal cell efficiency in materials that can be processed without expensive vacuum chambers

1% Dye Sensitized Cells

Advancing the efficiency and stability of inexpensive dye-based solar cells with novel nanostructures

22% Wafer Silicon

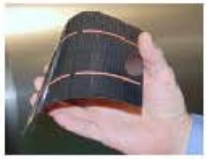
Combining thin amorphous and wafer silicon to make high efficiency cells with smaller total amounts of silicon

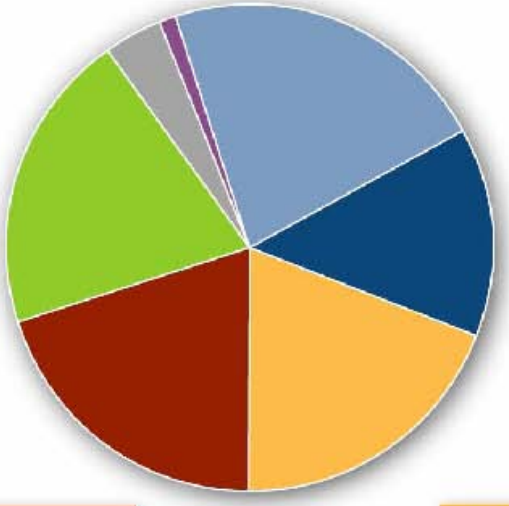
Developing new ink-jet printing methods for silicon electrical contacts

20% Thin Films (CIGS)

Supporting the novel manufacture of CIGS cells from ink-based precursors

Transferring discovery that highest performance material has nanostructured patterns into a fast and uniform manufacturing process





14% Concentrator PV

Devising strategies for making quicker, easier, less precise cells but maintaining record performance

Achieving record efficiencies (33.8%) even without concentration

20% Thin Films (CdTe)

Produced thinner films with same cell performance

Discovered a more durable way to make electrical contacts

19% Thin Films (Silicon)

Developing methods of making thin silicon film solar cells on inexpensive glass and at low processing temperatures

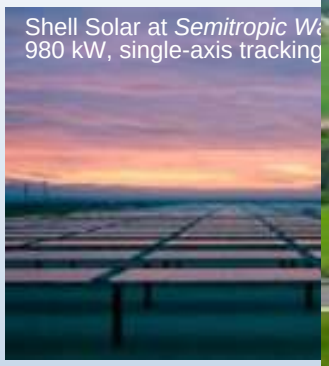
Moving Toward Our Destination


Ridge Vineyards PV Rooftop 65 kW, CA

WorldWater & Power, Irrigation System 267 kW, Seley Ranches, CA


RWE Schott Stillwell Avenue Subway Station, PV Canopy Roof, 250,000 kWh/yr, Brooklyn, NY


Powerlight, Bavarian community 6.750 MW, single-axis tracking Mühlhausen, Germany


Shell Solar at *Semitropic Wa*
980 kW, single-axis tracking


er & Geothermal Energy Co.
stewater Plant, 622 kW,
CA


PowerLight PowerGuard
536 kW, Toyota Motor C


op system,

Geothermal

Today's Status:

- 2,800 MWe installed, 500 MWe new contracts, 3000 MWe under development
- Cost 5-8¢/kWh with no PTC
- Capacity factor typically > 90%, base load power

DOE Cost Goals:

- <5¢/kWh, for typical hydrothermal sites
- 5¢/kWh, for enhanced geothermal systems with mature technology

Long Term Potential:

- Recent MIT Analysis shows potential for 100,000 MW installed Enhanced Geothermal Power systems by 2050, cost-competitive with coal-powered generation

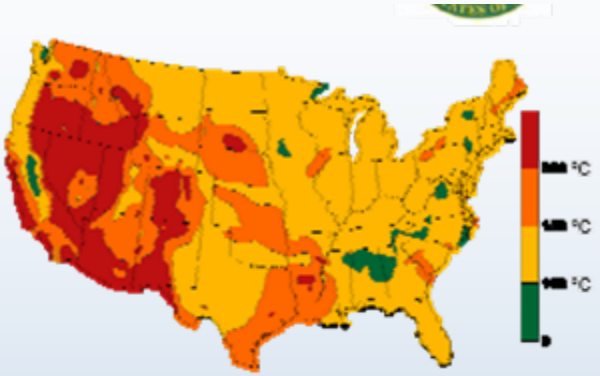
NREL Research Thrusts:

- Analysis to define the technology path to commercialization of Enhanced Geothermal Systems
- Low temperature conversion cycles
- Better performing, lower cost components
- Innovative materials

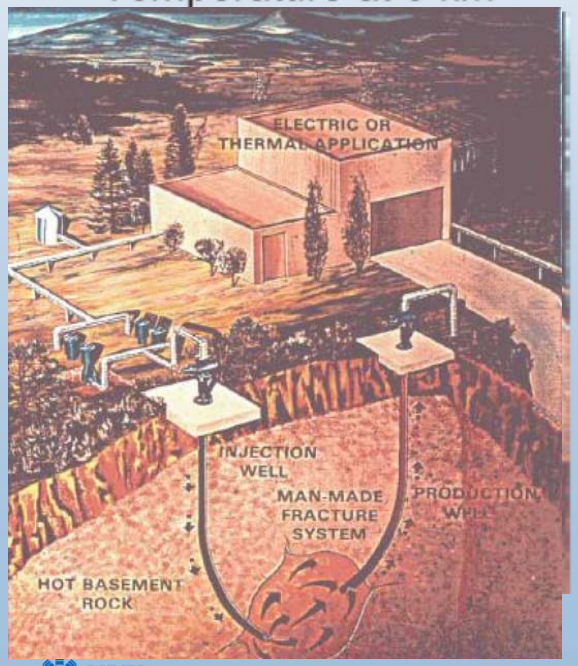
Source: DOE, NREL, 9/07

Enhanced Geothermal Systems (EGS) for Electricity Generation

- **Problem Technology Addresses:** Base load power generation with few or no emissions.
  - **Size of Problem:** Significant shortfall in projected U.S. power generation. Coal may not be able to meet the deficit.
- **Description:** EGS involves engineering a hydrothermal reservoir via fracturing and injection of water to extract heat from the earth.
- **Impact:**
  - Up to 10% (100 GWe) of the current power generation capacity can be from EGS, with potential to install much more.
  - There are essentially no carbon or other gaseous emissions and the geothermal resource is sustainable.
  - The resource exists across the nation.
- **IP Position:** Public domain, with the opportunity for many inventions.
- **Status:**
  - The EGS concept has been shown to be technically feasible at sites in several countries, including the United States.
  - The challenge is to improve EGS technology to ensure economic viability at commercial sites.
  - Field tests are required, starting with improving existing hydrothermal reservoirs, proceeding to expanding existing hydrothermal reservoirs, and ultimately creating reservoirs in challenging conditions.
  - For full-scale EGS development, about $50M to $100M/site.
  - Although the current working fluid is water, there exists the potential for other working fluids such as supercritical carbon dioxide, with attendant sequestration of the carbon. The carbon dioxide working fluid concept is patented and available for licensing, but field testing is required.

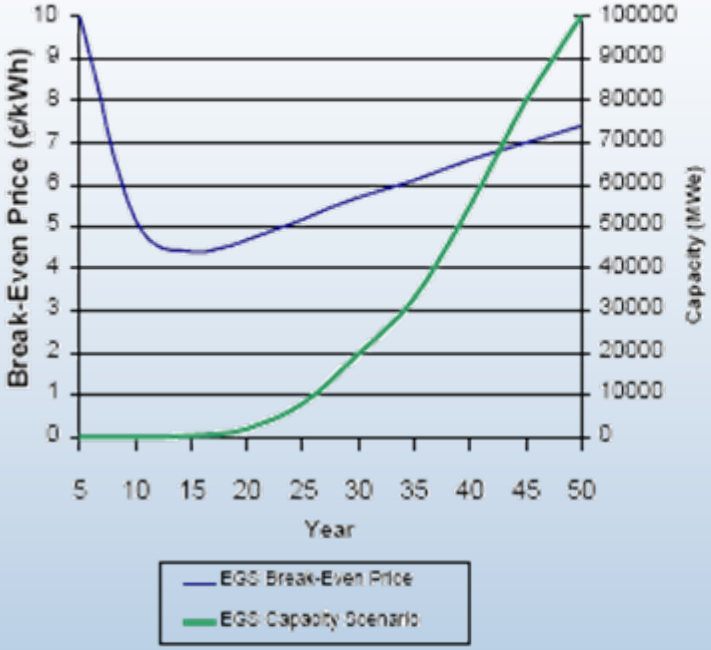


Temperature at 6 km



Source: DOE, August 2007

Enhanced Geothermal Systems Have Significant Potential



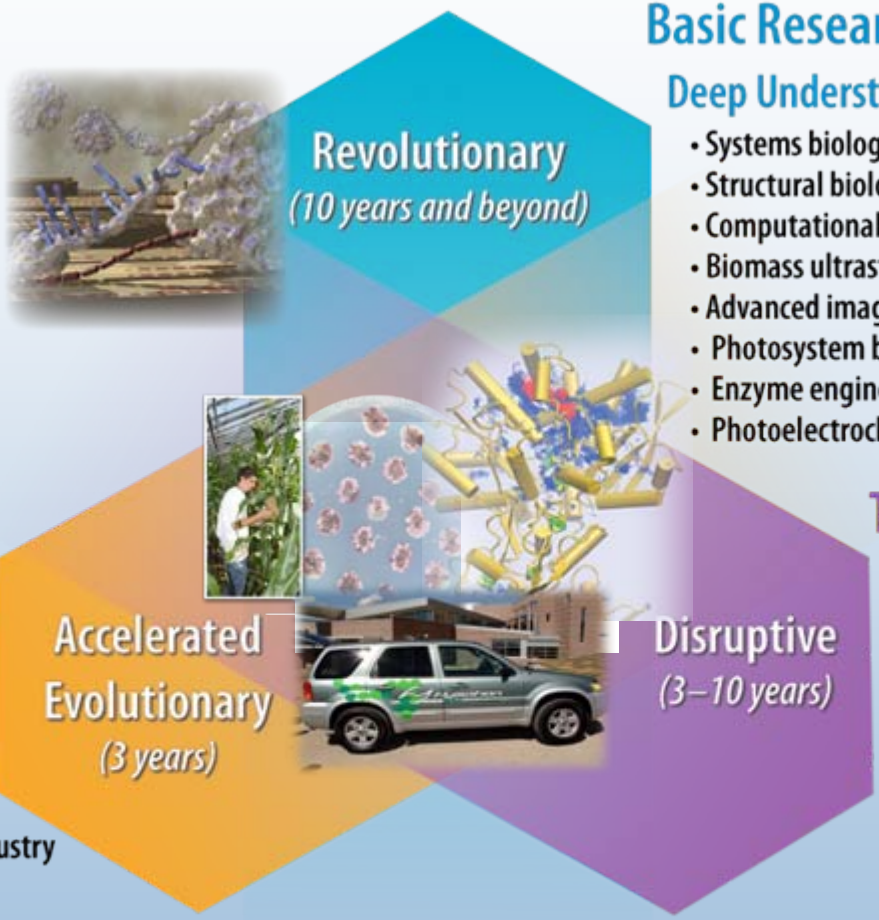
The geothermal resource can be used to generate electricity via enhanced geothermal systems (EGS), where hydrothermal reservoirs are created and heat is mined for conversion to electricity.

A commercial EGS project is under development at Cooper Basin in Australia using private sector funding.

MIT led an analysis by a panel of 18 international experts who concluded that it is possible to install 100 GW of EGS generation by 2050, with costs competitive with coal generated electricity. Geothermal generation is base load and has essentially no carbon emissions. DOE and national labs are performing an evaluation to define the technology developments required to enable private industry to commercialize enhanced geothermal systems.

Source: DOE, August 2007

Technology Investment Pathways



Basic Research Driven

Deep Understanding

- Systems biology & HTP
- Structural biology
- Computational science
- Biomass ultrastructure
- Advanced imaging tools
- Photosystem biochemistry
- Enzyme engineering
- Photoelectrochemistry

Industry Driven

Transportation Fuels

- Bioethanol pilot plant
- Technoeconomic analysis
- Performance testing for industry
- Biofuel cells
- Rapid biomass analysis
- Process unit testing

Technology Driven

Translational S&T

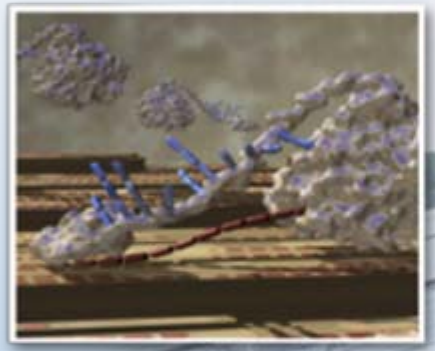
- Process consolidation
- Biological hydrogen
- Photoelectrochemical hydrogen
- Biomass pretreatments
- Mapping the plant cell wall
- Plant delignification
- Chemistry of biomass toxins

Source: NREL

Technology Innovation Challenges Remain

The Next Generation

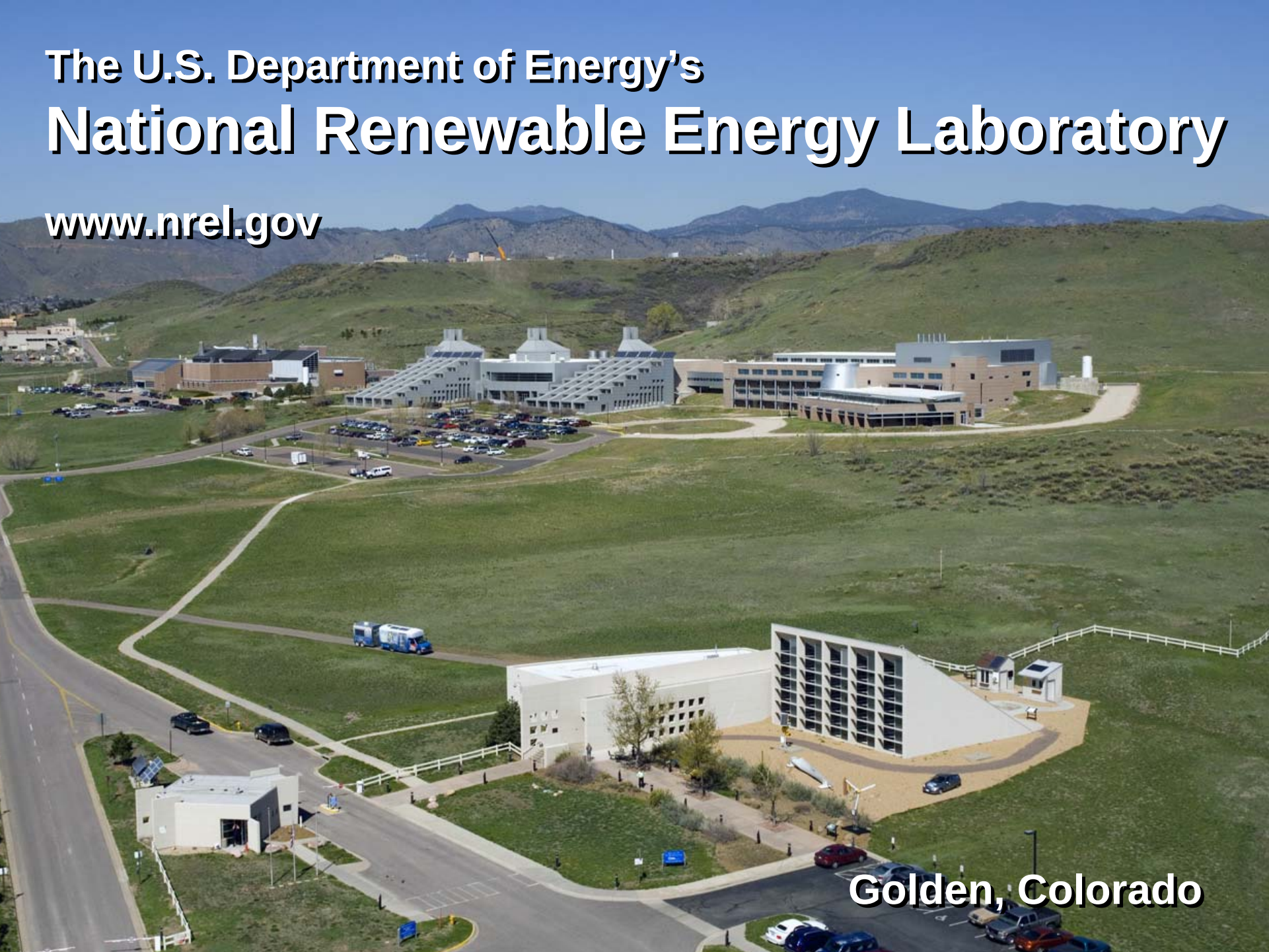
- Wind Turbines
  - Improve energy capture by 30%
  - Decrease costs by 25%
- Biofuels
  - New feedstocks
  - Integrated biorefineries
- Solar Systems
  - Improved performance through, new materials, lower cost manufacturing processes, concentration
  - Nanostructures
- Zero Energy Buildings
  - Building systems integration
  - Computerized building energy optimization tools



Promise of renewable energy is profound and can be realized if we…

- Aggressively seek a global sustainable energy economy
- Accelerate investment in technology innovation
- Acknowledge and mitigate the carbon challenge with the necessary policies

It is a matter of national will and leadership


The U.S. Department of Energy's
National Renewable Energy Laboratory
www.nrel.gov
Golden, Colorado